HF Radar Measurements of Ocean Surface Currents and Winds

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LONG-TERM GOAL

Our long term goal is to develop multifrequency, high frequency (HF) radar techniques and instrumentation for measuring surface currents, vertical shear, winds, friction velocity and waves in coastal regions and large lakes for scientific, civil and military applications. Our goal includes deployment of HF radar systems for air-sea interaction, coastal oceanography and ship detection research as well as the integration of HF radar measurements into coastal ocean models. A related goal is to investigate and develop ship detection and tracking techniques for multifrequency HF radar.

OBJECTIVES

The objectives of this project began with the construction and deployment of two and later three multifrequency HF radar instruments (called MCR for Multifrequency Coastal Radar) to Monterey Bay, California. Further experiment deployments were to the Virginia coast and to Lake Michigan for fresh water experiments (NSF sponsorship). The data collected at these sites are reduced, analyzed and interpreted to achieve the specific research objectives listed below:

1. Improvement of radar performance by upgrading hardware and software and developing improved transmit antennas, signal processing and flexible use of multiple frequencies

2. Improvement of HF radar estimates of surface currents, vertical shear, winds, friction velocity and waves by improved estimation algorithms that use knowledge of air-sea interaction physics

3. Estimate surface wind speed and direction using multifrequency HF radar measurements by exploiting air-sea interaction physics and HF radar measurements of vertical current shear

4. Ocean science investigations, including assimilation of HF radar data into coastal ocean models for circulation, chemical and biological properties as well as air-sea interaction studies

5. Use of continuing HF radar observations on Monterey Bay in observing ships to assess the usefulness of multiple frequency HF radar in ship detection and tracking.

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14. ABSTRACT
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APPROACH

This project requires an expert team of engineers and oceanographers from many institutions, including Peter Hansen and Lorelle Meadows (University of Michigan), Calvin Teague and Frank Ludwig (Stanford University), Dan Fernandez (California State University, Monterey Bay), Jeff Paduan (Naval Postgraduate School) and Kenneth Laws, Jessica Drake and Ben Van Houweling (University of California at Santa Cruz). This team designed, constructed, upgraded and deployed MCRs at sites on the Atlantic and Pacific oceans as well as the Great Lakes. We continually seek to deploy MCR systems for air-sea and ship observations in both short campaigns and long-term observations. A summary of our approach follows:

1. **Ocean science investigations**: participate in investigations of air-sea interaction, including momentum transfer and structure of the air and sea boundary layers and the assimilation of HF radar data into the coastal ocean circulation models

2. **Improve radar performance** by upgrading radar hardware and software, repairing and upgrading the radar antennas, especially transmit antennas, and comparing MCR with other HF systems

3. **Improve HF radar estimates of surface currents, current shear, winds and friction velocity** by developing improved estimation algorithms that use air-sea interaction physics, e.g., the Charnock relation, calibration and continued work on MUSIC and beamforming

4. **Estimate surface wind vectors using multifrequency HF radar** measurements by using statistical techniques, air-sea interaction theory and the HF vertical current shear measurements

5. **Use the continuing HF radar observations on Monterey Bay to observe ships** (especially known ships at known locations) at multiple HF frequencies, noting changes in detection and tracking performance with frequency, range, direction, ship type, etc.

WORK COMPLETED

1. **Observational program:** We strive to keep the MCR units in operation either at Monterey Bay, their ‘home site’, or employed in experimental campaigns elsewhere. During the last year two MCRs operated on and near Monterey Bay. This includes monitoring, maintenance and upgrades.

2. **Retrieval of vector winds using multifrequency HF radar measurements:** Partial least squares methods were used to estimate vector winds; estimates were compared to buoy measurements – see Drake et al. (2003) and Vesecky et al. (2003).

3. **Merging of HF radar current measurements made at different frequencies:** Development of a correction algorithm to remove bias caused by operation on different radar frequencies – see Vesecky et al. (2003).

4. **Calibration of HF radars using ship targets of opportunity:** With this technique antenna system response can be monitored and calibrations made frequently – see Fernandez et al. (2003).

5. **Communication of research results:** This year we presented and/or published eleven papers at seven major conferences and workshops on remote sensing and oceanography, including IGARSS and the Radio Oceanography Workshop, sponsored by ONR.

RESULTS

This year produced many new results with the analysis of past field observations as well as collection of new data and renovation of the Long Marine Laboratory field site near Santa Cruz CA. The field site at Santa Cruz required renovation and relocation as part of a major construction project at Long Marine Laboratory. This resulted in the development and deployment of new or modified transmit and receive antennas that are self-supporting, i.e., no guy wires. The resulting antennas blend more easily with the environment and are more acceptable to host institutions – a very important aspect in obtaining well-situated field sites on the coast. The new transmit antennas should have a longer service life and a longer time between failures.

Below are two new developments that are particularly important to the HF radar field. One concerns the retrieval of vector winds from multifrequency HF radar observations and comparison with buoy measurements and the other concerns the calibration of HF radar systems using echoes from ships of opportunity. Multifrequency HF radar measurements reveal the vertical current shear near the ocean surface. Thus, we anticipate that wind speed and direction can be estimated from MCR data since at wind speeds above a few m/s wind stress on the sea surface is usually the dominant factor in determining current magnitude and the vertical shear. Previous research has been successful in making wind direction estimates, but no really successful estimates of wind speed. For our initial effort we choose a linear, empirical prediction method known as partial least squares. This method seeks a wind component estimate based on a weighted sum of all the input data components. The weights are determined by a least squares procedure related to multiple linear regression and principal components methods. For the input data we used the surface currents at four observation frequencies as well as the wind direction estimated by the relative strengths of the first order Bragg peaks in the echo Doppler spectrum. We found that the upper most important inputs were from the upper two radar frequencies (13.5 and 21.8 MHz) that have effective depths nearest the surface (0.5 to 1 m and 0.3 to 0.5 m below the surface respectively). The differences between currents at different depths (vertical shear) were most important in determining speed and the Bragg line ratios most important for direction. We are working to bring more air-sea interaction physics to wind estimation and to merge the HF and buoy measurements of winds with coastal anemometers to construct a wind field over the Monterey Bay region.

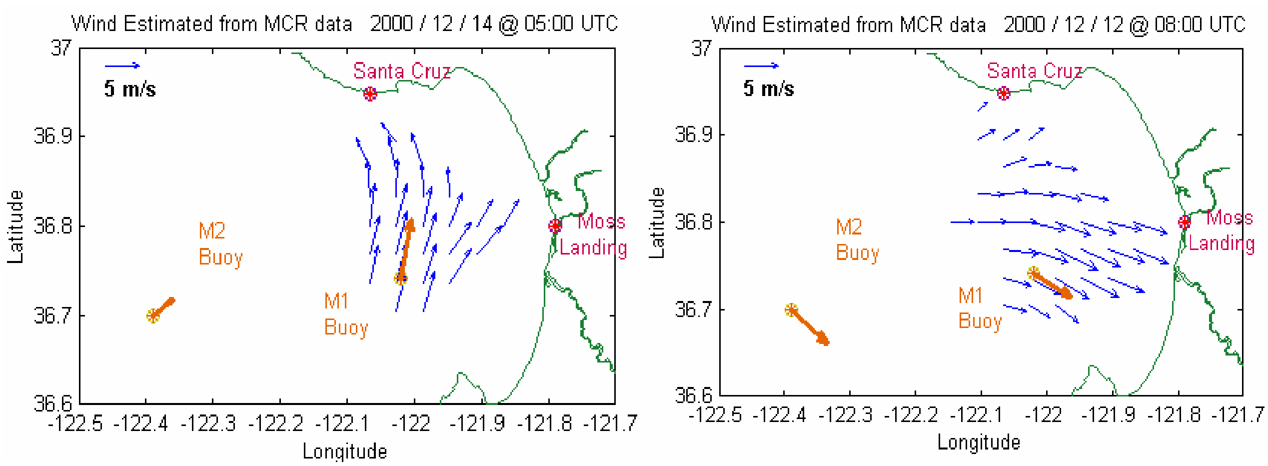

Fig. 1. Comparison of wind speed field estimates from MCR with buoy winds over Monterey Bay, California. The standard error of prediction SEP is ≈ 1.3 m/s. Left panel shows a southerly wind associated with an approaching low pressure system. Right panel (two days earlier) shows a more typical wind from the west to northwest.

We have developed an algorithm to use the echoes from ships of opportunity to determine the proper phase corrections for HF ground-wave phased array radar systems. Such HF radar systems are being used more and more extensively for measurements of coastal ocean surface currents and for ship tracking. In order to correctly determine the spatial bearing of the currents that such systems measure, antennas must be appropriately calibrated for amplitude and phase variations within the array. Phase and amplitude corrections are often accomplished through ship based transponder runs. Such calibration runs, however, require the use of a ship and thus are expensive and may not be done as frequently as is needed, such as if there are changes in the elements of the array or the local terrain. We have developed a technique that can potentially make use of ships of opportunity with unknown bearings to determine the required phase corrections for the array elements and to determine the bearing of the unknown ship. Fig. 2 shows an example run using transponder data collected with an 8-element loop receiving antenna array. Results thus far indicate that with this technique, for cases where the SNR exceeds 20 dB, the antenna phase corrections are less than 0.16 radians of the values obtained from a direct transponder run where the ship's bearing is known. When the ship's bearing is assumed unknown and is uniquely determined from the transponder echoes from the different radar frequencies, for cases where the SNR exceeds 20 dB, the results for the ship bearing are consistent to within 2-3°.

IMPACT/APPLICATION

Multifrequency HF radars have demonstrated their usefulness in measuring surface currents and current shear in the top few meters of the ocean. No other technique makes such measurements over a large area, at such low cost. We extended HF radar applications to fresh water and to mapping of friction velocity and wind vector. HF radar measurements are useful for real time environmental and ship tracking applications.

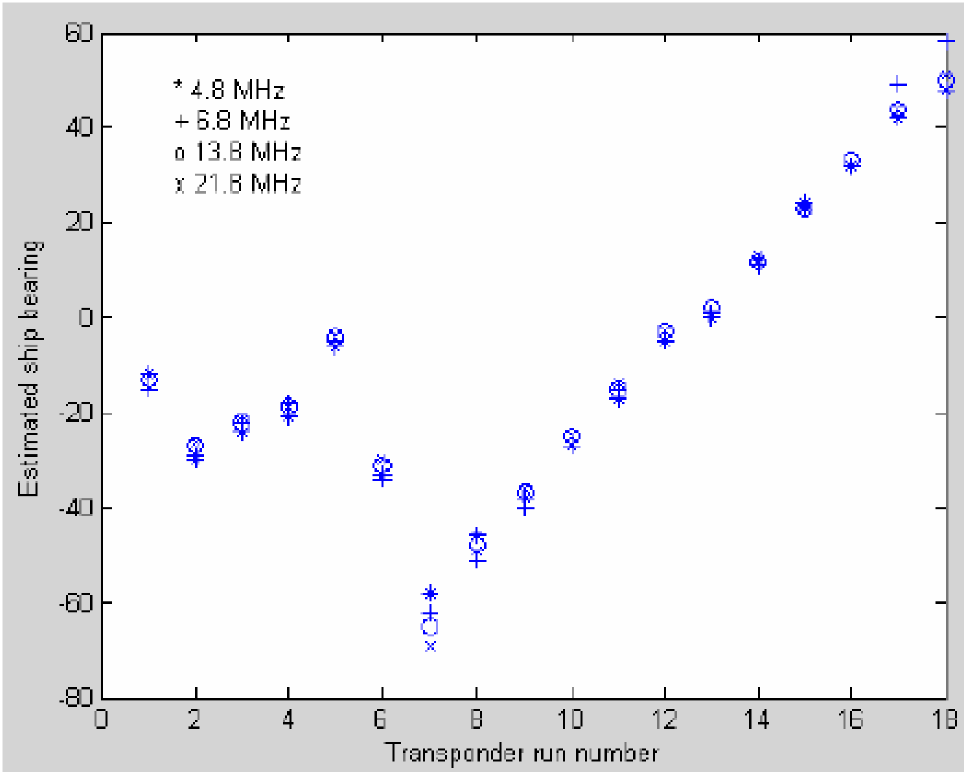

Fig. 2. Estimated ship positions based solely on transponder echoes. These positions have a spread of ≈ 3° and are consistent over all four operating frequencies indicating that the method is working properly.

RELATED PROJECTS

1. We participated in the Integrated Coastal Ocean Network (ICON) project (National Ocean Partnership Program), integrating in situ and remote measurements over Monterey Bay.

2. We currently participate in the Center for Integrated Marine Technology that brings together physical, chemical and biological oceanographers to make and interpret measurements relevant to the Monterey Bay Marine Sanctuary (NOAA)

PUBLICATIONS

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Vesecky, J. F., J. Drake, K. Laws, C. C. Teague and F. L. Ludwig, HF radar measurements of surface wind field, Oceans 2003, San Diego CA (Sept., 2003)

Papers presented at the ONR Radio Oceanography Workshop, March 2003 at Venice, Italy:

Vesecky, J. F. et al., Merging current data from HF radars operating at different frequencies (presented by D. M. Fernandez)

Drake, J. et al., Vector winds from multifrequency HF radar (presented by D. M. Fernandez)